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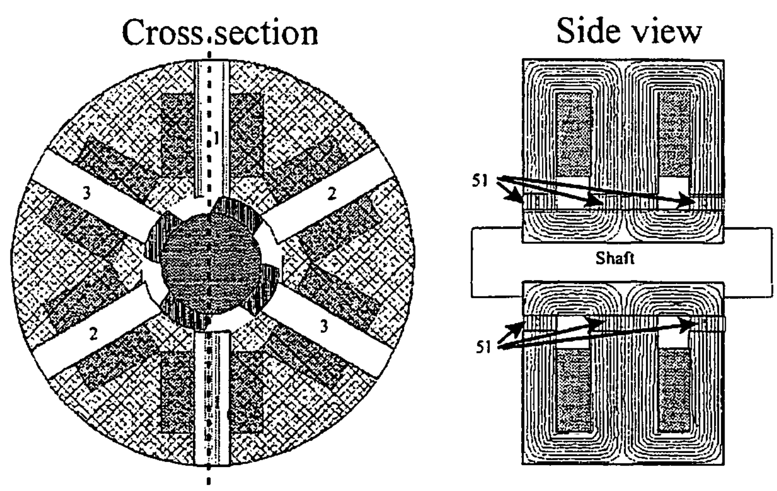
(54) Title: TRANSVERSE FLUX MACHINE WITH STATOR MADE OF E-SHAPED LAMINATES



(57) Abstract: In order to improve the torque per weight ratio in electrical machines for a lower price it is proposed to use a segmented stator design. The segmented stator design is based on general E shaped cores traditionally used for single-phase transformers and inductors. The E-cores has a coil around the centred leg and is assembled parallel to the rotor axis, which means it will function with the transverse flux principle. A radial flux principle can also be performed with the E-cores if the E-cores are divided into two U-sections with a full pitch winding in between them. A clear extra advantage with the E-cores is short flux paths meaning less steel has to be magnetised. For a low volume production standard E-cores can be used making the investment in production facilities smaller. The E-core machines using the transverse principle can have different pole-shapes such the normal force between the rotor and stator are significantly reduced. This makes unequal designs like a 3 stator- and 2 rotor-pole design practical possible.

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TRANSVERSE FLUX MACHINE WITH STATOR MADE OF E-SHAPED LAMINATES

FIELD OF THE INVENTION

The present invention relates to an electric rotating machine comprising a stator having a magnetic system comprising a plurality of individual core segments. In particular, the present invention relates to such a machine where the magnetic flux in the magnetic system is generated by windings arranged within outer legs of the core segments.

BACKGROUND OF THE INVENTION

An objective in the area of electrical machines in general is to make them more effective, such that they produce more torque with less weight and lower cost. Two electrical machine types have been in focus to full-fill this goal. These machines are the Permanent Magnet Transverse Flux Machine (PMTFM), and the switched reluctance machine (SRM). The PMTFM is well known for its high torque per weight ratio, but it is quite expensive and very difficult to manufacture because many parts are required. The SRM is one of the cheapest machines to manufacture and also has a reasonably good torque per weight density. Although the SRM has some good characteristics, it is not widely used mainly because of the high investment required to develop machines for an application and the high volume production and sales needed to lower the per unit cost of this development.

Electrical machines have traditionally been constructed by making a two dimensional cross-section in the X-Y plane and then extruding it in the axial dimension (z-axis) with a given number of non-oriented steel sheets. Such a two dimensional cross-section is shown in figure 1. The machine shown in figure 1 is a three-phase SRM with six stator poles 11 and four rotor poles 13. This machine has the disadvantage of long flux-paths in the stator yoke 15 from stator pole to stator pole and though the rotor yoke 12. The bobbin/needle wound coils 14 around the stator poles also present a disadvantage by extending past the steel stack thus making the machine longer. In addition, said coils are exposed and unprotected. With high magnetic saturation, which often is the case for an SRM, mutual couplings between the phases increases which makes exact control and design of the machine very difficult.

CONFIRMATION COPY

An alternative to the classical SRM in figure 1 is described in US 5.543.674. This machine is made with U/C-cores and ring coils and as a disadvantage requires 3 stacks to make a three-phase machine. The machine is characterised by the transverse flux principle where the flux travels from pole to pole in the axial direction and not a radial direction (in the X-Y plane) as the classical machine in figure 1. Electrical machines utilising the transverse flux principle are primarily known for a high torque per volume density where the torque ideally increases linearly with the number of poles. Due to the fact that 3 stacks are needed, this machine requires many parts and is thus very complicated to manufacture.

US 5.015.903 describes a switched reluctance machine with C/U-cores in the X-Y plane. The machine can be considered as a kind of alternative to the classical SRM where C/U cores are used. This machine has short flux-paths where only on a minor part of the stator yoke is magnetised during its operation. The machine uses two coils per C/U which require many parts. Also, the copper outside the C/U is not participating actively in torque production. Thus, the machine has the same disadvantages with many stacks and parts as the PMTFM, and the machine is therefore difficult to manufacture.

In US 4.748.362 an SRM with bifurcated teeth is presented. This machine can be considered as a classical SRM with C/U cores at the end of the poles. This machine does not have a short short-flux path, but it is known for the similar properties as the transverse flux machines where the torque doubles due to the bifurcated teeth (dual teeth/poles). The machine has disadvantages of long-flux paths, small space for the coils and coils that are difficult to install.

It is an object of the present invention is to design an electrical machine, which solves the above-mentioned problem.

SUMMARY OF THE INVENTION

The above-mentioned object is complied with by providing, in a first aspect, an electric rotating machine comprising a stator and a rotor. The stator comprises a magnetic system for generating a magnetic flux. The magnetic system comprises a plurality of individual core segments. The core segments have a body and a plurality of legs arranged substantially perpendicular to, and in extension of, the body. The legs are

separated from each other by air gaps, and the magnetic flux is generated by windings placed within outer legs of the core segments.

Thereby the windings will be shorter and concentrated inside the machine, which means no winding overhang like in the classical SRM. The outer sides on the two outer legs are not encircled by copper, which means the end-shields may be more simple to manufacture and assemble on the machine. Due to the fact that the poles and phases are separate no steel will be shared between the phases which makes the mutual couplings between phases small and thus exact control more simple.

In a specific embodiment the core segments are E-shaped, comprising a body and three legs, said windings being winded around said middle leg. Thereby a combination of the advantageous features seen in the PMTFM and SRM are obtained by using E-cores, which is widely used for inductors and single-phase transformers. E-cores are manufactured in standard shapes and uses grain-oriented sheet steel which has a higher flux-density and has lower losses than non-oriented steel used for electrical machine in general.

In another embodiment the core segments are U-shaped. The U-shaped core segments comprises a body and two legs, the body of the U-shaped core segments is placed perpendicular to the rotor axis and the windings are placed within the legs of the U-shaped core segments winded in an axis parallel to the rotor axis.

In a specific embodiment the body of said E-shaped core segments are placed in parallel to the rotor axis. In another specific embodiment the body of said E-shaped core segments are placed perpendicular to the rotor axis.

In an embodiment the endings of the legs are tilted increasing the gaps between the rotor and the endings of the legs. Thereby the air-gap flux is modified/optimised making the air-gap surface larger between the rotor yoke and the legs. This means less current is needed to magnetise the E-core and more torque can therefore be produced.

In a preferred embodiment the middle leg is wider than the two outer legs, preferably twice as wide. This has proven to be an advantageous embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be explained in further detail with reference to the accompanying figures in which:

Figure 1 shows a classical three-phase SRM with six stator-poles and four rotor-poles,

Figure 2 illustrates an embodiment of an E-core transverse flux machine where the principle of using E-cores is adapted to the classical SRM,

Figure 3 illustrates an example of the E-core principle used on an electrical machine with an outer rotor,

Figure 4 shows examples of E-cores where the air-gap is modified or optimised,

Figure 5 shows an example of E-core principle together with permanent magnets on the rotor e.g. a permanent magnet E-core machine,

Figure 6 shows an example of E-core principle with bias windings around the middle leg on the E-core,

Figure 7 shows an example of E-core principle with two donuts like biased windings and E-cores on both the rotor and stator side,

Figure 8 shows an embodiment of a two-phase machine, with a divided E-core with a full-pitch winding around the divided centre leg, and

Figure 9 shows an embodiment of a three-phase machine, with a divided E-core with a full-pitch winding around the divided centre leg.

DETAILED DESCRIPTION OF THE INVENTION

The electrical machines described in the prior-art have disadvantages that the present invention removes by using standard E-cores. The present invention is described in the following.

Figure 2 illustrates an embodiment of an E-core transverse flux machine where the principle of using E-cores is adapted on the classical SRM. E-cores are traditionally used for single-phase transformers or as rectifier inductors and are characterised by having the shape of the letter 'E' and being constructed from oriented sheet steel which results in a higher flux densities and lower losses. E-cores are also made and sold in standard geometric forms, which can be a large advantage when producing small quantities of the E-core transverse flux machine.

By using E-cores 21 and its yoke/rotor section 22 the flux-path is short when compared to the classical SRM as the steel in the stator-yoke and rotor-yoke is non-existent. The yoke/rotor section is mounted on the shaft 23. The coils 24 will be shorter and concentrated inside the machine, which means no winding overhang like in the classical SRM. The outer sides on the two outer legs are not encircled by copper, which means the end-shields 25 may be more simple to manufacture and assemble on the machine. Due to the fact that the poles and phases are separate no steel will be shared between the phases which makes the mutual couplings between phases small and thus exact control more simple. Classical SRM combinations of phases, stator and rotor poles may be applied on the E-core machine and the machine will still only have one stack. The machines described in US 5.543.674 require the same amount of stacks as the number of phases and will thus be more difficult to manufacture. The machines in US 5.543.674 will also need a large amount of parts.

As mentioned the E-core machine can be constructed with various combinations of phases and poles, but the machine also has additional advantages in an outer rotor design as shown in figure 3. The E-cores in the stator are simply flipped 180 degrees and additional rotor segments are used. The extra rotor/yoke segments do not add much to the total weight but there will be more attractions between the stator and rotor poles during each revolution. This will ideally improve the torque per mass density of the machine by a factor 4 when using 16 rotor segments, but in practice a factor in a range from 2-3 should be obtained.

The laminations used for E-core machine may differ from standard E-cores used for transformers and in figure 4 examples is shown where the air-gap flux is modified/optimised.

The example shown in figure 4-A is a triangle air-gap where the surface in the air-gap is larger. This means less current is needed to magnetise the E-core and more torque

can therefore be produced. Figure 4-B shows a principle where flux is crossing the rotor in the axial length which may reduce vibration and acoustic noise from the machine. Furthermore, some uneven stator/rotor pole combinations with this axial crossing flux may be more advantageous because there won't be an unequal pull on the rotor. An example of this arrangement could be an axial flux 3 phase E-core machine with 3 E-cores and two yoke/rotor segments. The air-gap shape in figure 4-C is simply a combination of figure 4- A and figure 4-B.

The E-core principle may also be used for other machine types such as a permanent magnet machine. In figure 5 an E-core permanent magnet machine is shown, where permanent magnets 51 are mounted on the rotor.

An extra field, like the machine with permanent magnets, can also be obtained with biased windings, where examples are shown in figure 6 and in figure 7. In figure 6, a biased winding 5A1 is added on the centred leg on all the E-cores. All the individual biased windings are then preferably coupled in series and connected to a DC voltage source. With help of the voltage amplitude or the DC current in the biased windings is it then possible to control the magnetisation in machine. This could be very advantageous if the machine is used as a generator who has to deliver the same voltages at different speeds. Another advantage is the fact that no brushes are required to the magnetisation circuit i.e. the DC biased windings. This is normally required for synchronous machines with variable magnetisation. With the biased assisted field is it also possible to supply the motor with a converter given bipolar currents. The biased windings can also be formed as two donut types shown in figure 7. The donut type windings 5B1 should be attached to the stationary part. To increase the winding area is it preferable to have double E-core poles.

It has to be mentioned that the coils can be wound around the two E-core outer legs, but it will not provide the same level performance as one coil on each E-core centre leg when equal amounts of windings are used.

The E-core idea with the coils around the centred leg can also be modified to the classical X-Y laminated machines. The E-Core is dived into two sections with a coil in the centre functioning as full pitch winding. In figure 8 and in figure 9 are examples of a two and three-phase versions shown. These machines can be considered as unique short flux-path machines having best features from US 5.015.903, US 4.748.362 and US 5.545.938 combined in one single segmented machine. In US 4.748.362 it was

mentioned that bifurcated teeth gives a minimum number of coils, which was 4 for a two phase machine.

The elements on figure 8 and 9 are full-pitch coils 61 having end-turns 62. Each of the coils makes a phase, but for a larger pole number is it possible to use more coils to perform a phase. The E-core is divided in stator segments 63. Between the stator segments preferably non-magnetic and dielectric material 64 may be used such the assembly is more simple. The non-magnetic material can be equipped with channels 65 such for instance water can pass though and cool the machines. But also auxiliary electrical wires may pass though in the channel.

With the modified E-core machine according to the present invention only two coils are required for a two-phase machine and a much larger slot area is available for the coils. The modified E-core machine has very large advantages in applications where the diameter is small in relation to the stack. In this case the copper in the end-turns has a minimum influence. Typical applications needing an electrical machine with a small diameter and long length are submersible pumps, servo machines, oil-well equipment etc. Similar to the E-core transversal flux machine the mutual couplings for this modified E-core machine is small.

Although the present invention has been described in connection with preferred embodiments, it is not intended to be limited to the specific form set forth herein. On the contrary, it is intended to cover such alternatives, modifications, and equivalents, as can be reasonably included within the spirit and scope of the invention as defined by the appended claims.

CLAIMS

1. An electric rotating machine comprising a stator and a rotor, said stator comprising a magnetic system for generating a magnetic flux, said magnetic system comprising a plurality of individual core segments, said core segments having a body and a plurality of legs arranged substantially perpendicular to, and in extension of, the body, said plurality of legs being separated from each other by air gaps, said magnetic flux being generated by windings arranged within outer legs of the core segments.

2. An electric rotating machine according to claim 1, wherein said core segments are E-shaped, said E-shaped core segments comprising a body, a middle leg, and two outer legs, said windings being arranged around said middle leg.

3. An electric machine according to claim 1, wherein said core segments are U-shaped, said U-shaped core segments comprising a body and two legs, the body of said U-shaped core segments being placed substantially perpendicular to a rotor axis and where windings are arranged inside the two legs of the U-shaped core segments and arranged around an axis parallel to the rotor axis.

4. An electric rotating machine comprising a stator and a rotor, said stator comprising a magnetic system for generating a magnetic flux, said magnetic system comprising a plurality of individual E-shaped core segments each generating separate magnetic flux.

5. An electric rotating machine according to claim 4, wherein the E-shaped core segments comprises a body, a middle leg, and two outer legs, said windings being arranged around said middle leg.

6. An electric rotating machine according to claim 2 and 5, wherein the body of said E-shaped core segments are arranged substantially parallel to a rotor axis.

7. An electric rotating machine according to claim 2 and 5, wherein the body of said E-shaped core segments are arranged substantially perpendicular to a rotor axis.

8. An electric rotating machine according to claim 2 and 5, wherein endings of the legs are tilted thereby increasing the air gaps surface between the rotor and the endings of the legs.

9. An electric rotating machine according to claim 2 or claims 5-8, wherein the middle leg is wider than the two outer legs.

10. An electric rotating machine according to claim 9, wherein the width of the middle leg is approximately twice the width of the two outer legs.

11. An electric rotating machine according to claim 2 and 5, further comprising one or more DC-biased windings arranged around the middle leg of the E-shaped core elements.

12. An electric rotating machine according to claim 2 and 5, further comprising one or more DC-biased donuts windings arranged in each E-core slots.

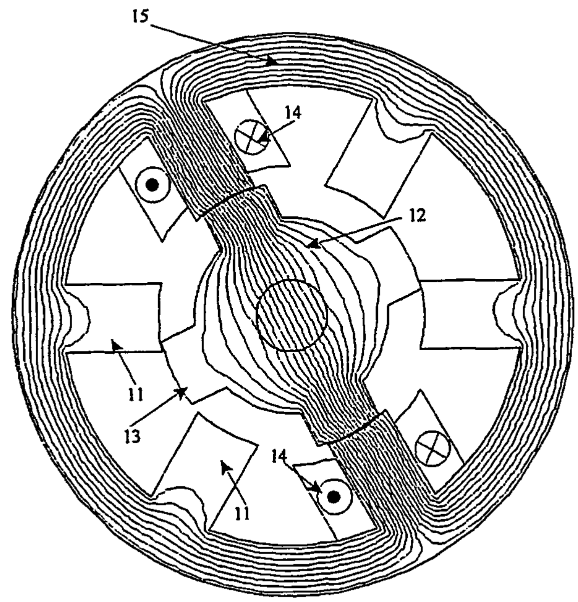
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Fig. 1

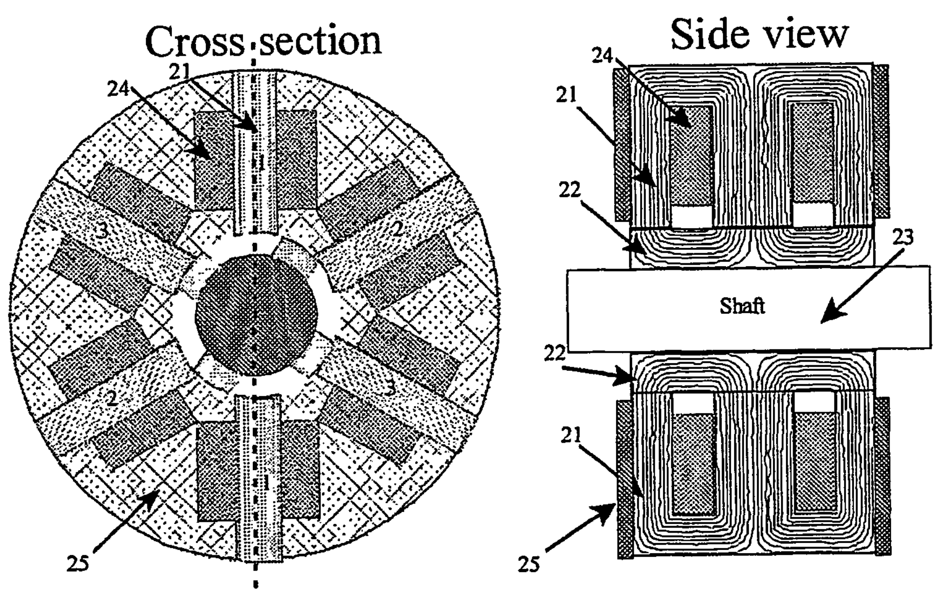
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Fig. 2

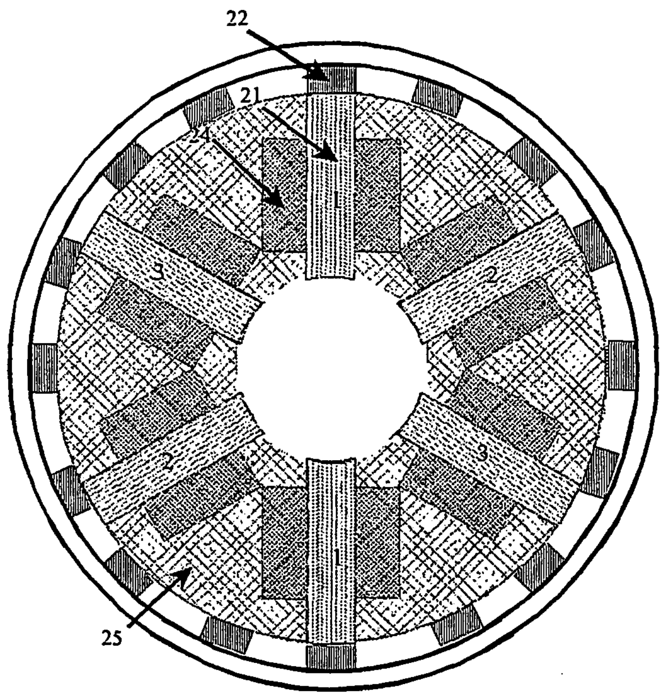

Fig. 3

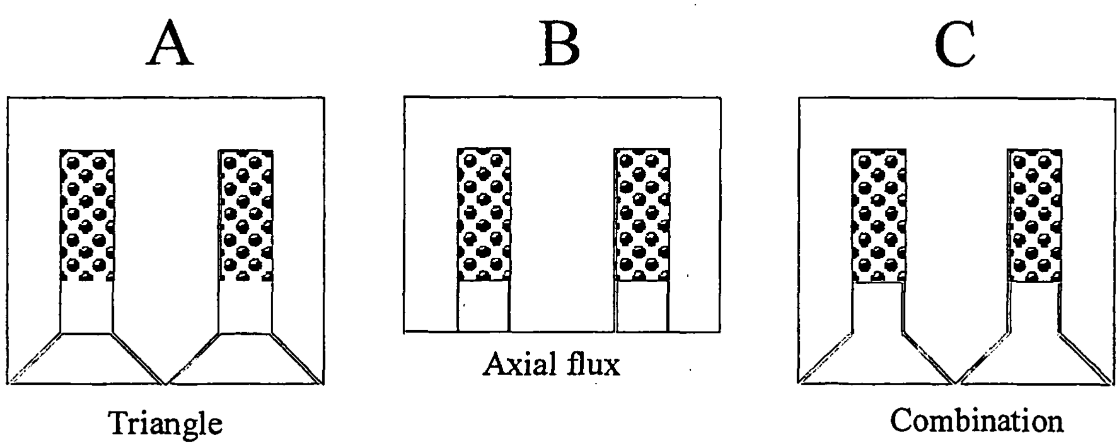

Fig. 4

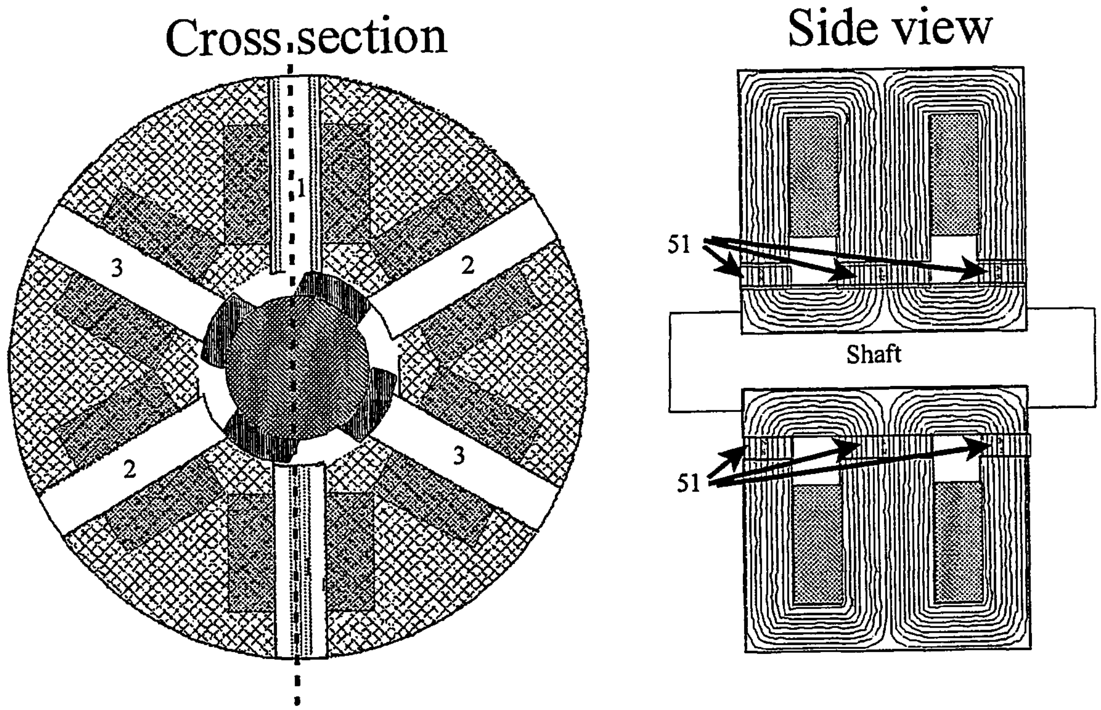

Fig. 5

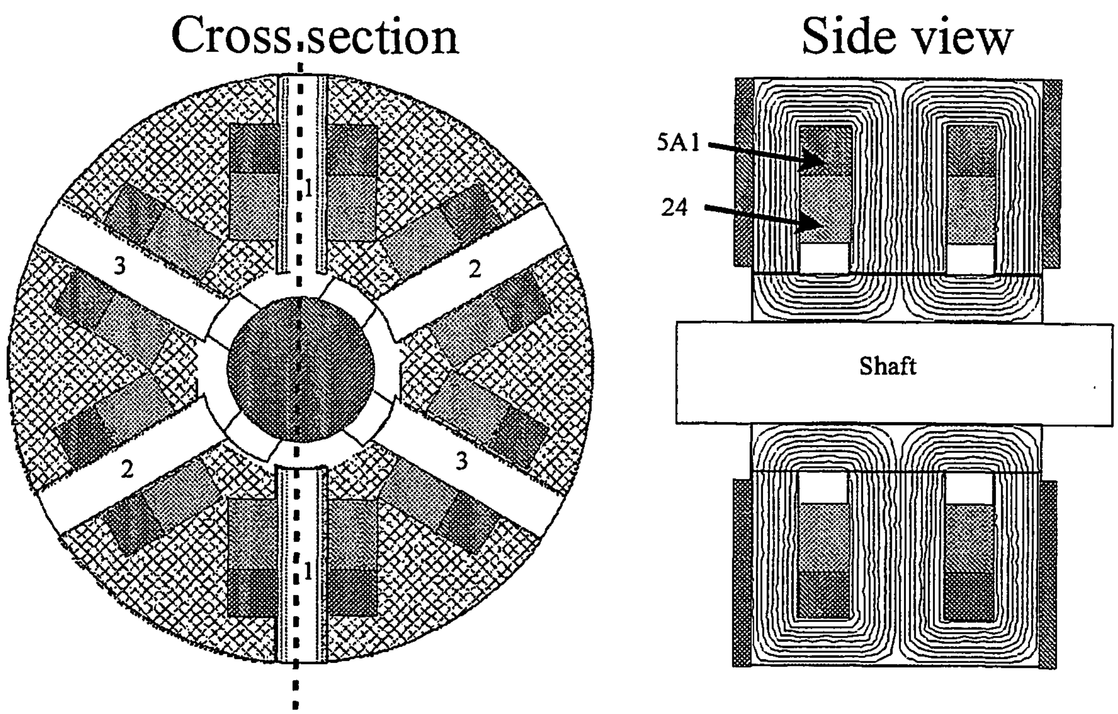

Fig. 6

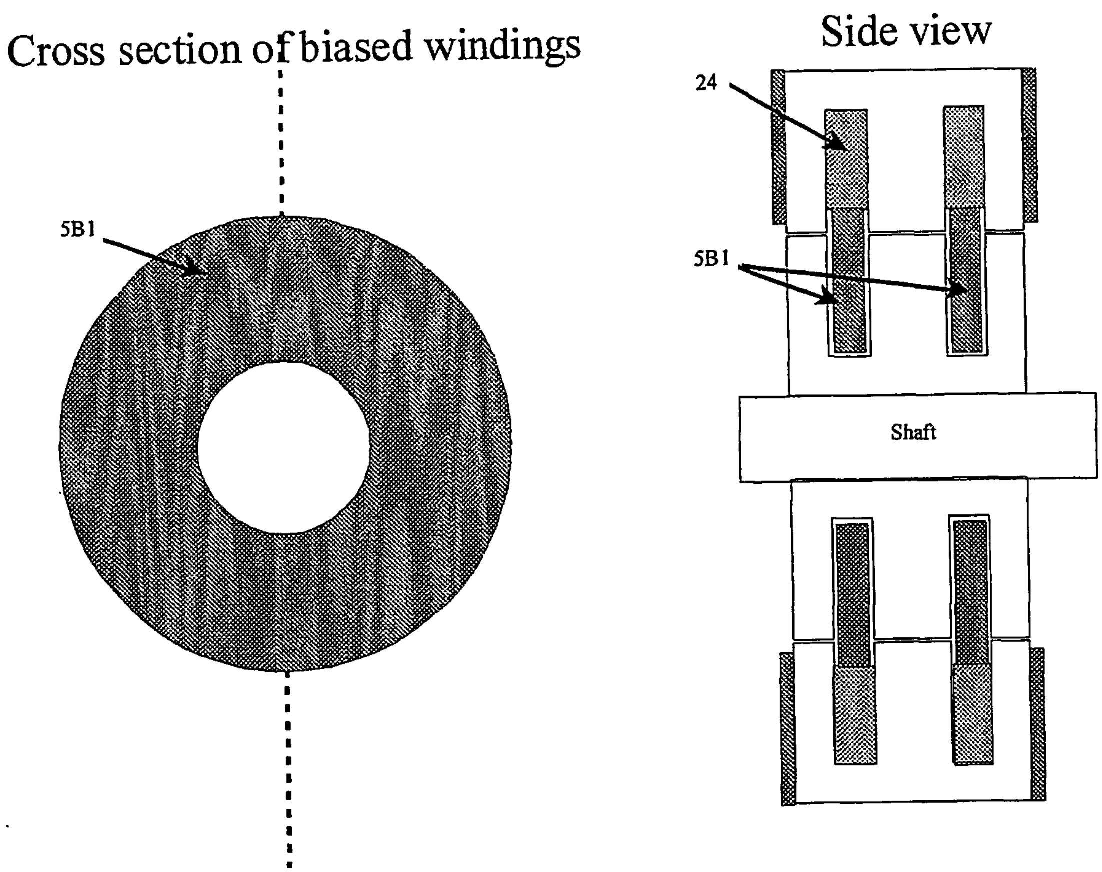

Fig. 7

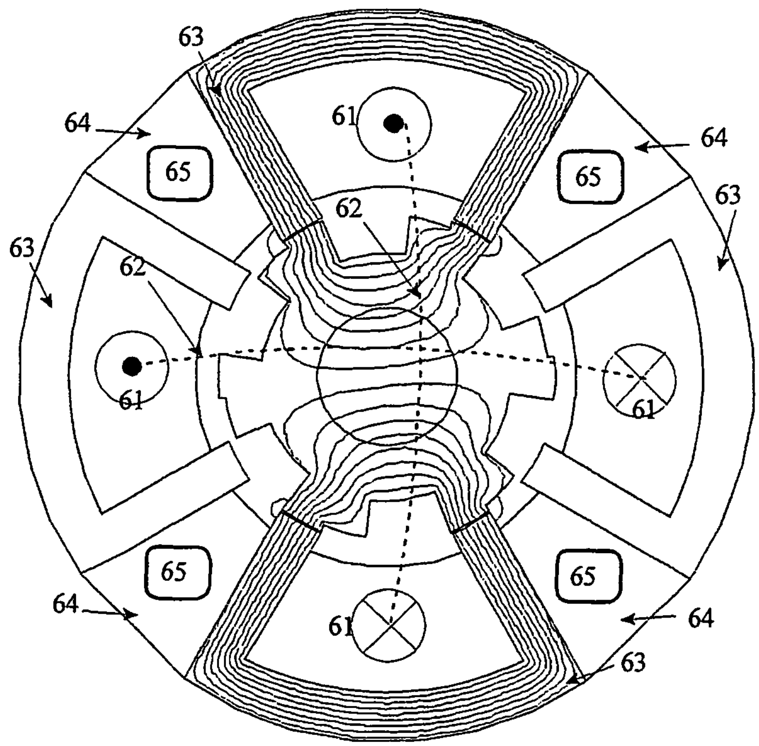

Fig. 8

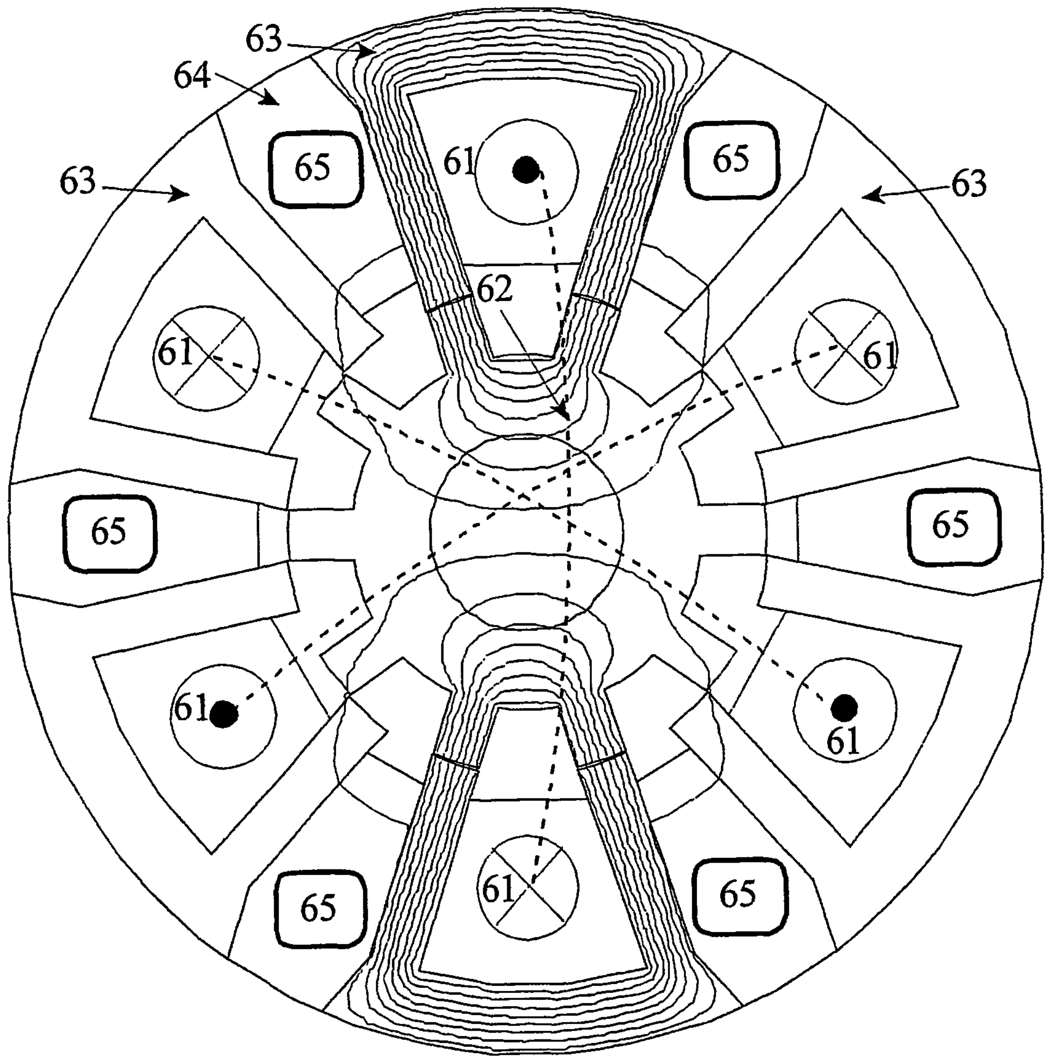

Fig. 9

INTERNATIONAL SEARCH REPORT

International Application No
PCT/DK 02/00300

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H02K1/14

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

WPI Data, PAJ, EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 009, no. 310 (E-364), 6 December 1985 (1985-12-06) & JP 60 144122 A (SHIBAURA SEISAKUSHO:KK), 30 July 1985 (1985-07-30) abstract; figures 2-4 ---	1-12
A	WO 99 01924 A (HILL WOLFGANG) 14 January 1999 (1999-01-14) page 4, line 26 -page 5, line 12; figure 1 ---	1-12
A	US 4 748 362 A (HEDLUND GUNNAR) 31 May 1988 (1988-05-31) figure 3 -----	1-12

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
4 July 2002	22 07 2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Tomas Erlandsson

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